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An Automatic Fume Extraction System for Welding Operations

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ABSTRACT: *In this study, an effective fume extraction system was designed and constructed for safe protection during welding process at the Mechanical Engineering Workshop of the Akwa Ibom State University. The development of the project enabled a good, clean and comfortable working environment for technologists, lecturers and students performing welding operations at the Mechanical Workshop. It also helps to protect others who are not involved in welding operation but engaged in other important workshop related activities such as reading, documentation, machining, wood carving, design conceptualization et cetera, from inhaling polluted air which are caused by the fumes released during welding operation. The steps adopted in the design and fabrication of the automatic portable fume extraction system was sketching, 3D drawing and fabrication. A sensory powered control switch system was used to enable a faster, on-time response as compared to the manual configuration for effective suction of the fume and gases. The result obtained during the testing of the double filter system in the fume extractor proved that cotton cloth with an efficiency of 40% and 4.4g of fume particles trapped per hour is a better filter material compared to fibre which has an efficiency of 22.9% with 3.2g of fumes particles trapped per hour, it was observed from our result that the weight of filtrate captured by the fume extractor is dependent on the number, type and grade of electrode used, the supply voltage and duration of welding operation. The automatic fume extraction system is economical and offers the best solution in tackling hazards caused by fumes and gases not only in welding but in other allied processes that promote fumes formation.*

Keywords: *Extraction, Filter, Fume*

I. INTRODUCTION

Welding is one of the most commonly used industrial processes all over the world. Welding provides a powerful manufacturing tool for high quality joining of metallic components. Research has revealed that an estimate of 11 million workers worldwide have welding as their primary occupation and a total of 110 million people are exposed to fumes as a result of welding processes (IARC, 2017).

Welders exposed to a variety of air borne contaminants arising from welding process and other operations in the workplace suffer when they inhale fumes that come from welding spot, known as welding fumes. Welding fumes are metal oxide particles formed by the cooling of subsequent condensation of hot metal vapor generated during welding. The composition of which mainly depends on the chemical composition of the base metal and the electrode (Mohan, Sivapirakasam, Bineesh and Satpathy, 2014).

Epidemiological studies as reviewed by Antonni (2003), indicates that welders exposed to these welding fumes have an increased risk of developing lungs and airway diseases such as bronchitis, airway irritation, and metal fume fever.

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Oberdorster, Ferin, Gelein, Soderholm, and Finkelstein (1992), where concern with metal joining process, they found out that workers were affected by intrinsic asthma, extrinsic atopic asthma or asthma with allergic Broncho pulmonary aspergillosis were hankie typed for the HLA A, B, and C loci. These diseases will usually lead to death or sometimes inability to participate actively in welding process.

In view of the problems arising from the severe effect of welding fumes on health, this study seeks to provide solution to the challenges associated with welding fumes with the idea of designing and fabricating an automatic efficient extraction system with filtration for welding operations, therefore making Akwa Ibom State University Mechanical Engineering Workshop safe and healthy for welders, lecturers, technologists and students.

II. METHODS

In order to achieve the aim and objectives, the methods employed in executing this project involves the use of traditional fabrication processes in carrying out the proposed project, along with the use of Computer Aided Design (CAD) software for mechanical modelling of parts and components, (electrical and electronics components and circuit), and the use of Programming Integrated Developer Environment (IDE) to write codes. This codes are embedded in the hardware that interacts with other parts to execute the control logics, so as to achieve the automatic operation of the proposed solution according to the project objective of designing an automatic fume extraction system which is capable of eliminating and controlling the pollution rate of welding fumes in the environment.

III. DESIGN

Designing a fume extraction system means finding the perfect solution for a specific need, taking into account all the characteristics of the location, the activities that take place there and the pollutant production methods. These variables will be taken into account for the correct design of a fume extraction system in an industrial context, and the possible configurations will be developed.

An extraction system is necessary and mandatory to protect the health of operators in all industrial contexts where operations such as welding operations are routine. The correct design of the system leads to a series of further benefits:

i. The workplace is more orderly, clean and comfortable
ii. Production is leaner and faster
iii. The final product has a clearly superior quality.

Designing a Fume Extraction System: The Variables Involved

The design of each fume extraction system begins with the evaluation of the objective variables relating to the type of industrial environment, the activities carried out and the fumes produced. More specifically, the following must be taken into account:

i. The room in which the extraction and filtering system will operate
ii. The number of workstations and their locations (for example, are they near or far from each other)
iii. The type of production of the pollutant (fume), i.e. the methods of emission
iv. The size of the parts to be welded (for example: small household appliance components or long steel pipes)
v. The welding or tin-plating frequency and their average duration.

Efficient Design Guidelines

There are basic guidelines for efficient design of fume extraction systems thanks to the experience accumulated in the field, WORKY is able to provide a specialized service for the design of a fume extraction system, that is, for choosing the right system for different types of industrial realities.

In order to profess solution to the problems stated in chapter one of this paper and achieve the objectives of

this work, the following methods and procedures will be used starting from the design process and concept to the final process of adding aesthetics. All these processes and methods to be employed are discussed in this chapter.
The aim of this project as outlined in chapter one of this work include the design and fabrication of a smart and energy efficient fume extraction system. This is to be achieved by designing and producing a physical prototype based on an optimised design from CAD data generated in the design process.

DESIGN CONSIDERATION

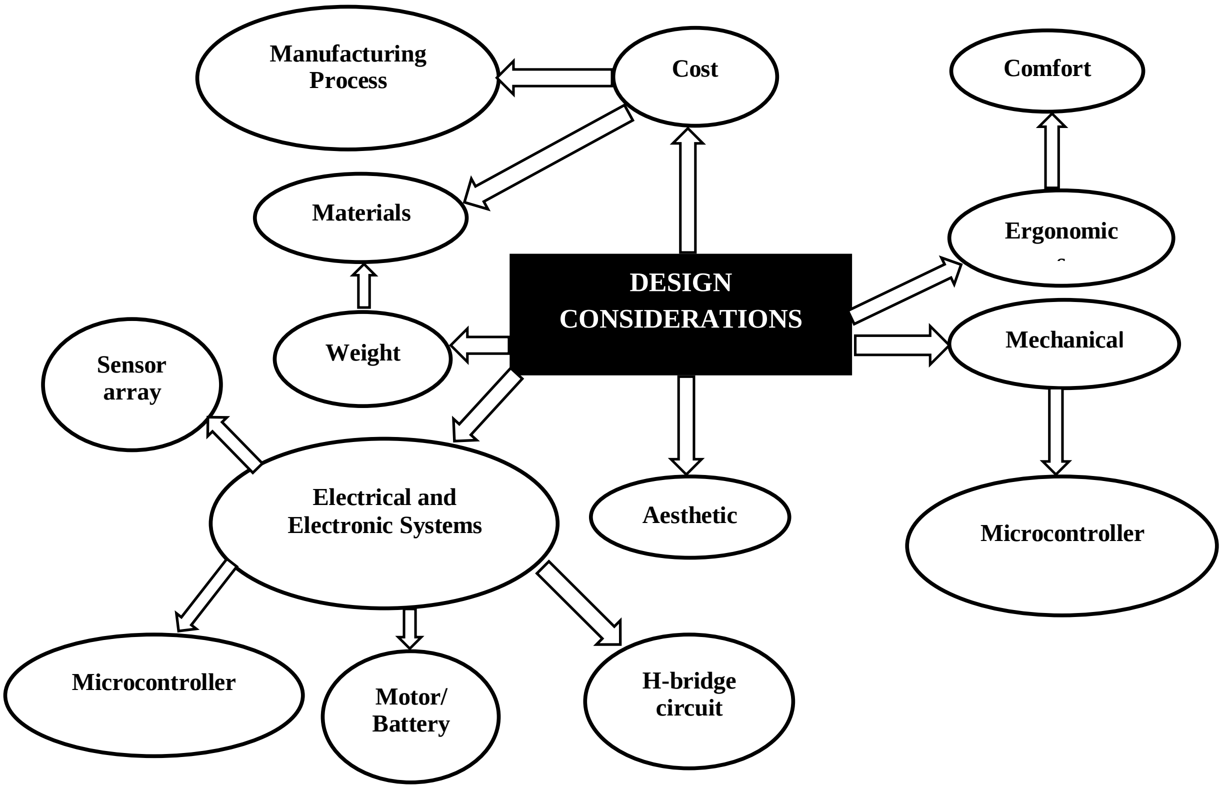

Figure 3.1: Important Factors in Design Considerations

Design Concepts

The design concept adopted for this work is a simple suction system which makes use of the venturi effect to create a negative pressure at the suction nozzle, sucking in the gasses around the nozzle. To make the system smart and energy efficient, a microcontroller in conjunction with a current sensor is used to automatically turn on the system when the fume generating operation (welding) is initiated, and turn off the system when the activity is over. The design concept of the fume extractor in different view is depicted in Figure 3.2, 3.3 and 3.4 respectively.

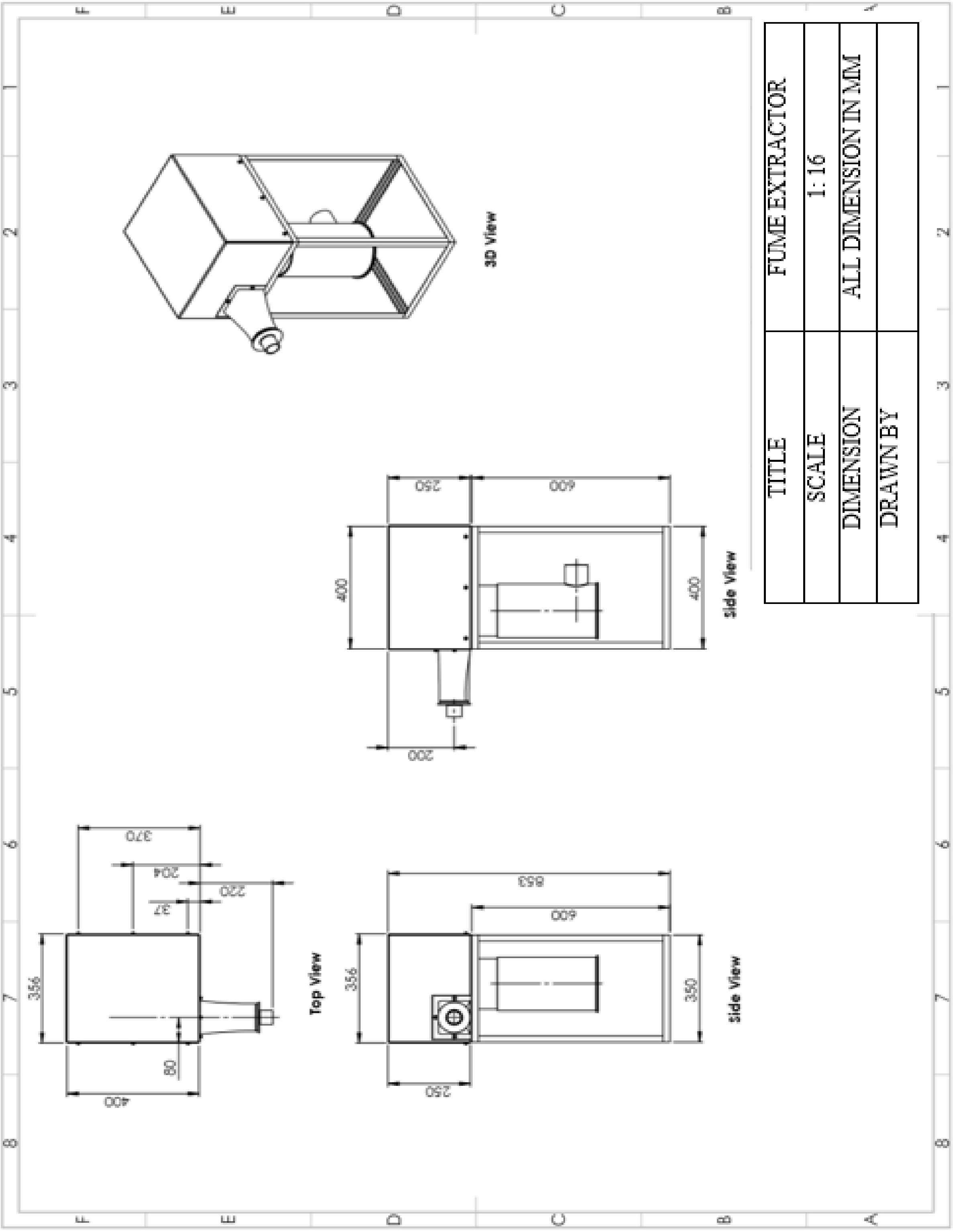

Figure 3.2: Conceptual Design Model showing the Top, Front and Side View of the Fume Extractor with Complete Dimensions

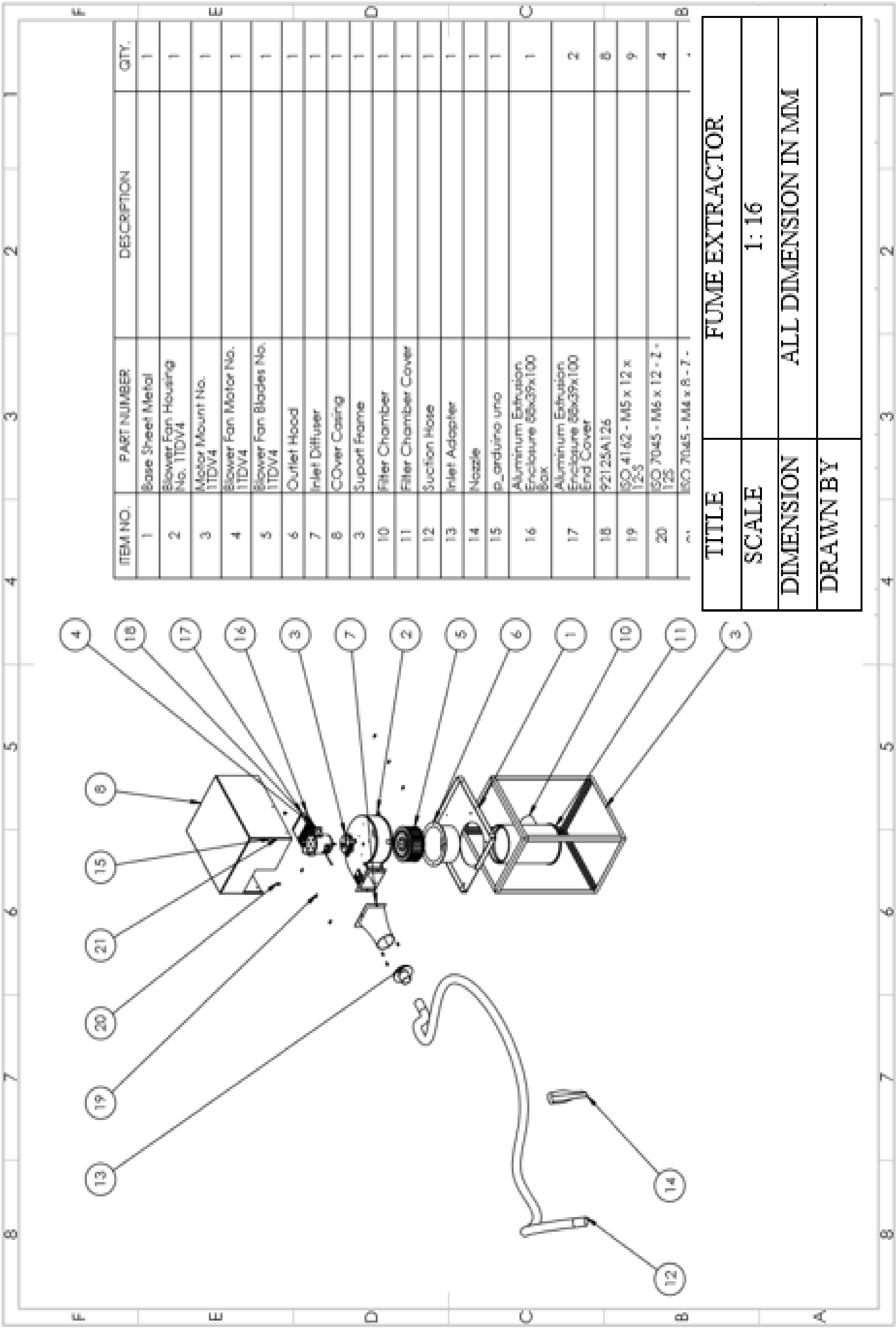

Figure 3.3: Conceptual Design Model Showing the Exploded View of the Automatic Fume Extractor.

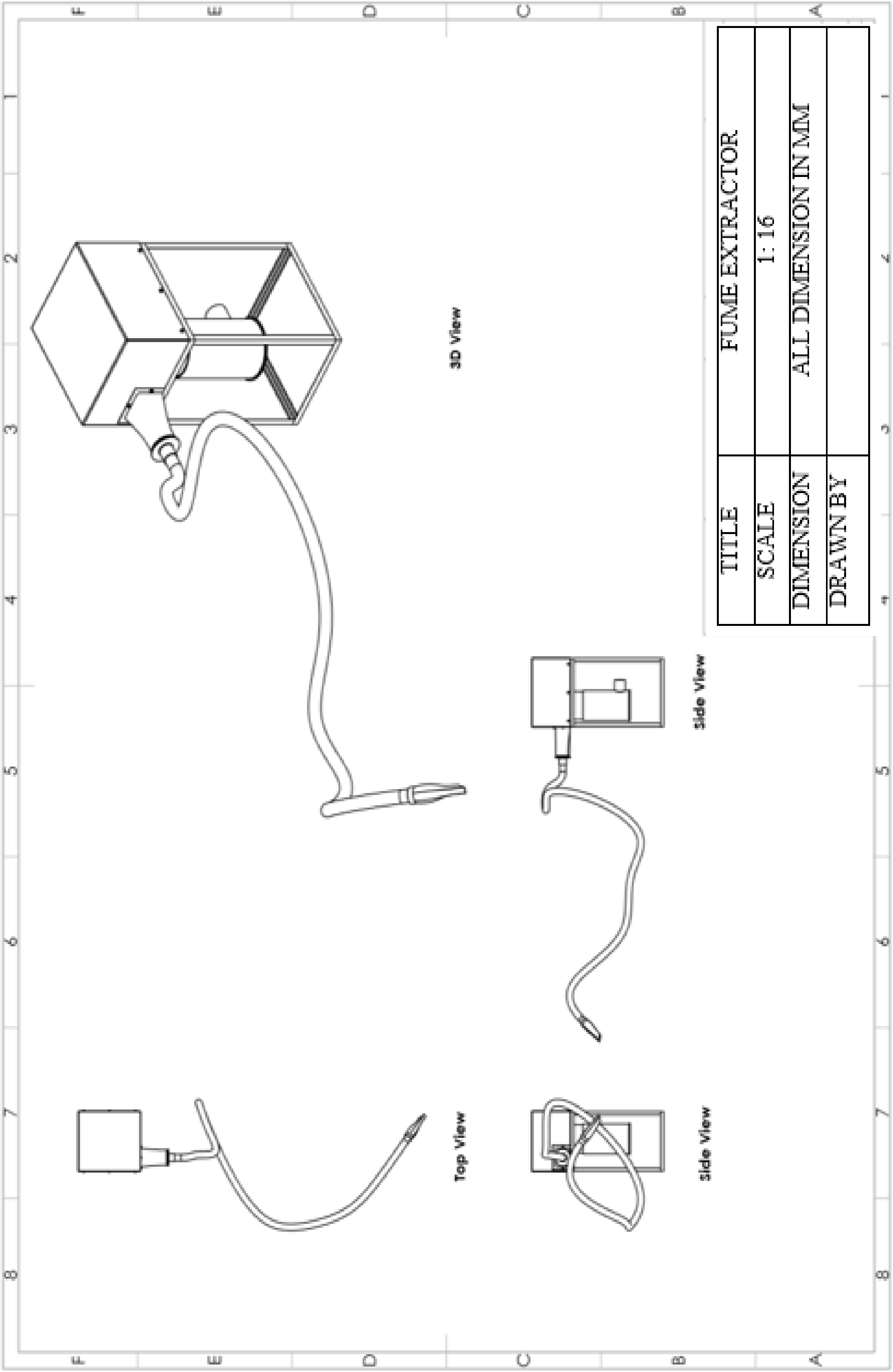

Figure 3.4: Conceptual Design Model showing the Top, Front and Side View of the Fume Extractor

Model Design

The model designs are discussed here where Solid Works Design software is used for mechanical design, modelling and rendering, Arduino Uno for hardware programming, Fritzing for circuit design and development. The steps and processes that will be involved are described in details below.

Mechanical Model

The mechanical model of the system is done using Solid Works and AutoCAD Software to create working drawings, and photo-realistic models of component parts which had to be fabricated to achieve the objectives of this works. The frame is designed by arranging angle bars in a cuboid, 506 x 309 x 309 mm. The end of the angle bars is chamfered for proper lapping.

A flat bar is used to partition the top part of the frame vertically to prevent vibration and ensure firmness. Mild steel pan is cut to the required dimension of the closing surfaces. A mild steel pan rolled in a cylindrical form to a diameter of 55 mm on top of the frame to accommodate the capture hood which serves as inlet of fume into the machine. The air filter is designed to be inserted into the tank from the top pan and then locked from the top. The centrifugal blower will be installed on one side of the extractor tank and held in place by a suitable fitting made out of square mild steel pipes.

The exploded view and the assembled mechanical rendered model of the fume extractor is shown in Figure 3.5, 3.6 and 3.7 respectively.

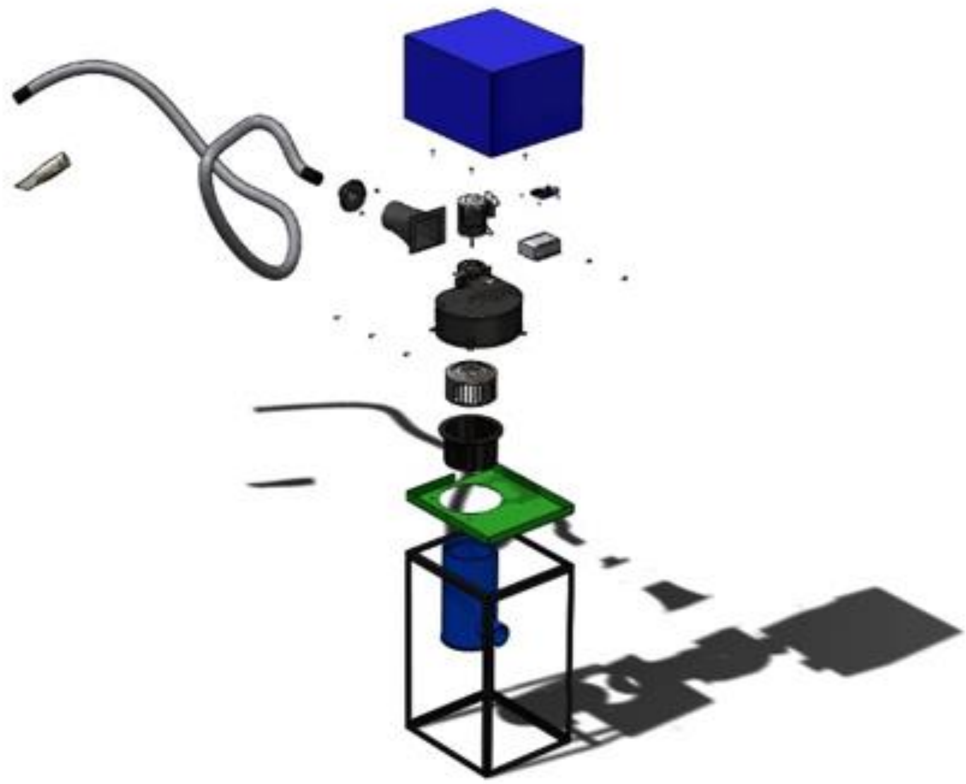

Figure 3.5: Exploded View of Mechanical Rendered Model Using Solid Works.

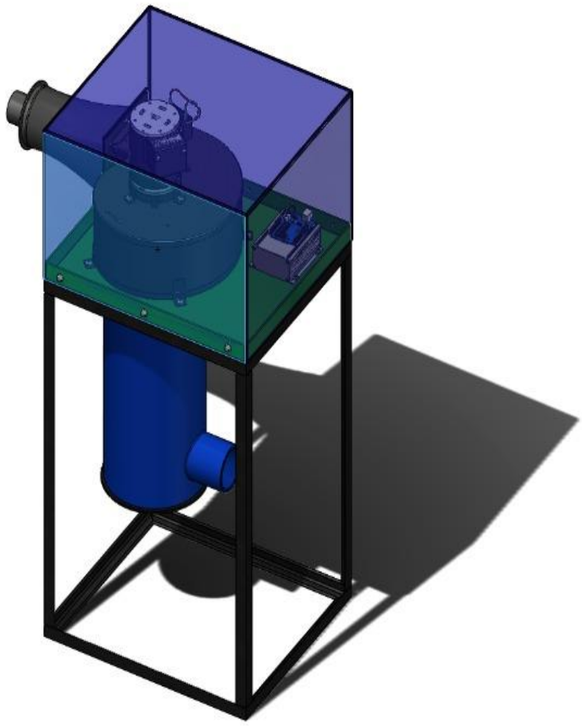

Figure 3.6: Mechanical Rendered Model Using Solid Works of Fume Extractor

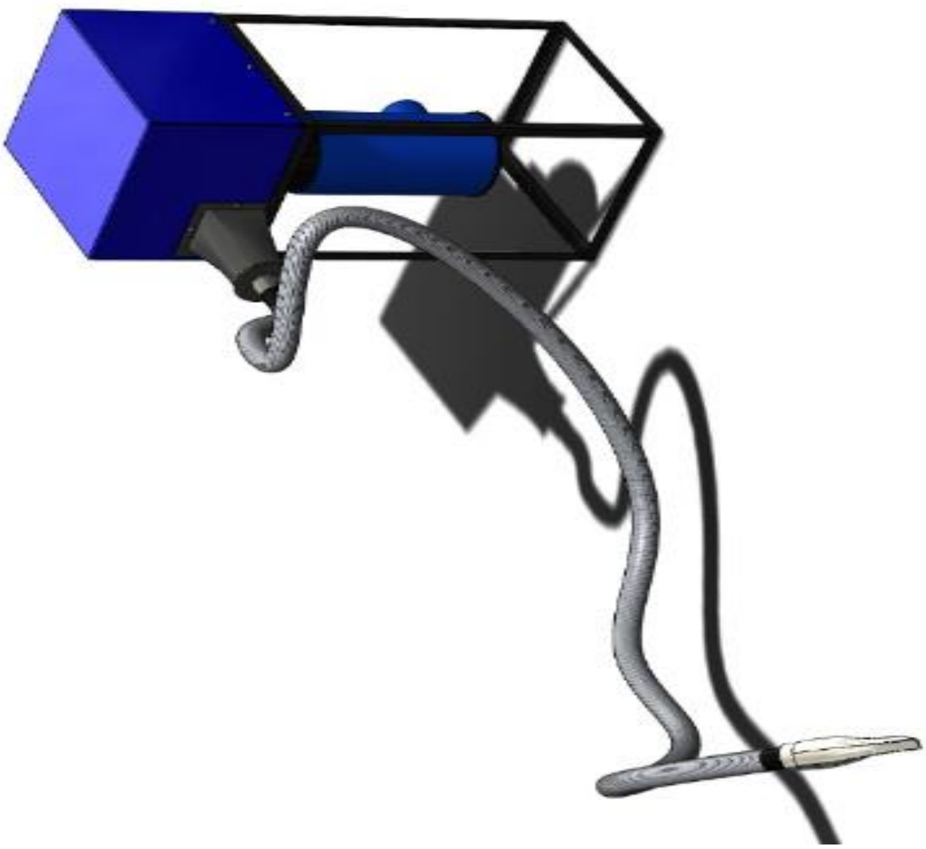

Figure 3.7: Mechanical Rendered Model Using Solid Works of Fume Extractor with Suction Nozzle.

Design Calculations

Ventilation Rate and Fume Removal

The ventilation rate required to maintain a concentration of a fume in the occupied zone with the threshold limit value (TLV) can be calculated from equation (Mansour and Mohammad, 2010) based on the material balance (McDermott, 1985)

$$Q_O = Q_{exh} + \frac{[G(10^6)(1-e) - Q_{exh}(C_{oz} - C_O)]}{K_C(C_{oz} - C_O)} \quad - \quad - \quad - \quad (3.1)$$

Where: Q_o is the Air supply rate (m/hr.), Q_{exh} is the Local ventilation exhaust rate (m^3/hr), G is the rate of fume generation (kg/hr), n is the Local ventilation capacitor efficiency (unit less), C_{oz} is the desired concentration of fumes, gas particulates in occupied zone (mg/m^3), C_o is the concentration of fumes, gas particulates supply in air (mg/m^3), K_c is the contaminants removal efficiency (unit less) and e is the coefficient which represents the fraction of time the welder spends at the workstation.

$$K_c = (C_{UZ} - C_O)/(C_{UZ} - C_O) \quad - \quad - \quad - \quad - \quad (3.2)$$

where:

C_{uz} is the Concentration of fumes in the upper zone air (if air is evaluated from this zone) or in the exhausted air (mg/m3). The quantity of fume or gas G (kg/hr.) generated in the space can be calculated using one of the following equations (Francis, 2016).

$$G = R_1 \times T_{ar} \quad - \quad - \quad - \quad - \quad - \quad (3.3)$$

where:

R_1 is the fume (gas particles) generation rates, kg/min and T_{ar} is the average arc time per hour for the welding process used (min/hr).

Blower Selection

After careful considerations of the various types of fans available, the radial-bladed fan is selected as the one suitable for the extractor blower. This fan is characterized by high pressure, medium flow and continuous power increase and very suitable for handling dust-laden, moist air/gases. These fans are equally known to be well suited for high temperatures and can handle heavily contaminated airstreams (Shan-jun *et al.,* 2011).

Analysis of the Centrifugal Blower Impeller

Principle of conservation of momentum states that the total momentum of a system in any one direction remains constant unless acted upon by an external force in that direction (Khurmi & Gupta, 2006).

At the inlet of impeller, momentum

$$AIM = M \times W_1 \times r_1 \quad - \quad - \quad - \quad - \quad (3.4)$$

At the exit of impeller, momentum

$$AEM = M \times W_2 \times r_2 \quad - \quad - \quad - \quad - \quad (3.5)$$

by principle of conservation of momentum (Khurmi and Gupta, 2006), equation (3.4) is equal to equation (3.5).

$$Torque = Mrv \quad - \quad - \quad - \quad - \quad - \quad (3.6)$$

where;

M is the mass of air flowing through (kg/s), r_1 is the Radius of inlet blade (mm), r_2 is the Radius of outlet W_1 (mm), is the angular velocity of the inlet impeller, W_1 is the angular velocity of the outlet impeller, V = velocity of the impeller. According to (Francis, 2016).

$$M = \rho \times Q \quad - \quad - \quad - \quad - \quad - \quad - \quad (3.7)$$

Where; M is the mass flow rate, ρ is the density and Q is the volume flow rate.

$$T = Q \times \rho \times r \times v \quad - \quad - \quad - \quad - \quad - \quad (3.8)$$

As obtained from the machine design, prime mover type is a single phase induction motor, speed of blower = 1650 rpm, air duct length = 300 mm, air duct cross section = 35 mm in diameter, outlet blade diameter = 157 mm, inlet blade diameter = 165mm,

Velocity Triangle Position at the Impeller Inlet and Outlet

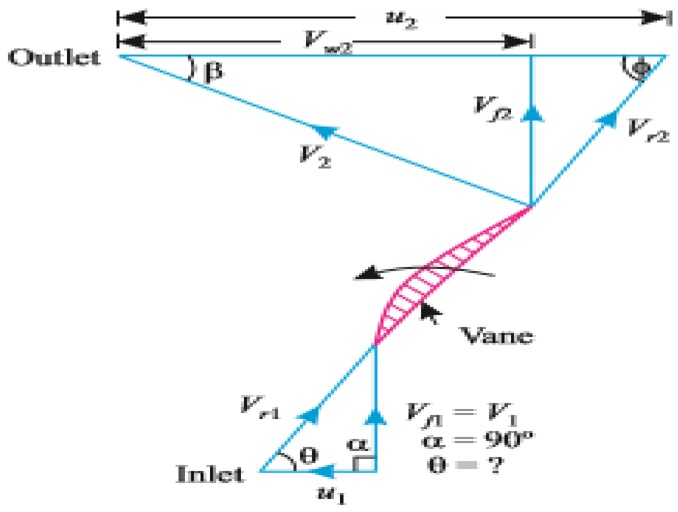

Figure 3.8: Velocity Triangle Position at the Impeller Inlet and Outlet (Rajput, 2008).

Where, V_1 and V_{r2}= Radial velocity at inlet and outlet, u_1 and u_2 = Tangential velocity at inlet and outlet, V_{r1} and V_{r2} = Relative velocity at inlet and outlet, ∅ = 30°

Angular Velocity $(\omega) = \frac{2\pi N}{60}$ - - - - - - - (3.9)

$= \frac{2\times3.142\times18000}{60}$

= 1885.2 *rad/s*

Tangential Velocity (u_2) = ωr_2 - - - - - - - (3.10)

u_2 = 1885.2× 0.0176

u_2 = 33.35 m/s

Considering the velocity diagram in Figure 3.6, tan ∅ = $\frac{V_{r2}}{u_2}$ - - - (3.11a)

Where ∅ = Vane angle at outlet = 30°

Radial Velocity of outlet impeller (V_{r2}) = u_2 × tan ∅ - - - - (3.11b)

V_{r2} = 33.35 × tan 30°

V_{r2} = 19.25 m/s

Mass Flow Rate (M) = $Q_o \times \rho$ - - - - - (3.12)

Where, Q_o= Air supply rate and is given as 0.828 m^3/s and ρ = Density of air =1.2kg/m^3

M = 0.828 × 1.20 = 0.994 kg/s

Torque (T) = $Q_o \times \rho \times r \times v$ - - - - - (3.13)

Where *r* = radius of outlet blade and *v* = Tangential Velocity.

T = 0.828 × 1.20 × 0.0176 × 33.35 = 0.5834 Nm

Power (P) = $T \times \omega$ - - - - - - - -

(3.14)

P = 0.5834 × 1885.2

P = 1099.82 watt ~ 1.48 hp

Fabrication Process

The fabrication process to be use in the production of the proposed project involved the traditional fabrication processes carried out in their order of precedence. The processes include; marking out, cutting, machining operations (drilling and filing), joining and surface finishing. These processes are explained below;

1. **Marking Out**

Marking out was the first step in the fabrication process. It involved marking out the dimensions of the materials according to the working drawing. The shaft was marked along its length for cutting. The 3/4" angle was also marked according to specification from the working drawing using marking tools (chalk, meter rule, meter tape, square, protractor, divider, and scriber). The holes were marked out for drilling using centre punch.

2. **Cutting**

The cutting process involves cutting the materials according to the marked out outlay on the materials. Cutting will be done using a hacksaw, wood saw, wood chisel and cutting machines. The 3/4" angle will be cut at points marked out for cutting.

3. **Machining**

The machining process that was carried out in the fabrication process includes drilling operations using vertical drilling machine, and surface grinding operations using hand held grinding machine (angle grinder). The drilling operation involved the use of drilling machine to drill holes for the passage of bolts to secure components to the frame, while grinding operations involved grinding off rough edges and protrusions after welding.

4. **Joining**

Welding was adopted as the major process of joining materials. The 3/4" angles used for the frame will be joined by welding. All metal joining processes will adopt welding operation except those for component which employed the use of bolts and nuts. The joining of electronic components on the Vero board will be done by soldering.

5. **Surface Finishing**

After careful deliberation and consideration, painting was selected as the best choice for surface finishing operation due to cost implications. Painting offers protection against corrosion of metallic parts used in the fabrication process and gives aesthetics value to the automatic fume extraction system

IV. RESULTS

The calculations used in determining the choice of selecting individual components employed in the fabrication and analysis of the double filtration system of the Automatic Fume Extraction System.

Table 4.1:Results from Impeller analysis

SN	Parameter	Units	Values
1.	Radial velocity of the inlet impeller (V_1) (flow is assumed to be non-directional)	m/s	0.000
2.	Radial velocity of the outlet impeller (V_2)	m/s	19.25
3.	Radius of inlet blade (r_1)	m	0.0088
4.	Radius of outlet blade (r_2)	m	0.0176
5.	Impeller tangential velocity (u_2)	m/s	33.35
6.	Angular velocity (ω)	rad/s	1885.2
7.	Volume flow rate of air (Q_o)	m^3/s	0.828
8.	Density of air (ρ)	kg/m^3	1.200
9.	Mass flow rate (M)	kg/s	0.994
10.	Torque (T)	Nm	0.584
11.	Power required to move air (P)	hp	1.48

Table 4.1 above shows the performance analysis of the centrifugal blower selected for the automatic fume extraction system for effective suction of welding fume particle at the source, during welding operation

Analysis of a Double Filtration System.

Mass of filter material = M_0

Mass of filter material and trapped fume = M_1

Mass of trapped fume = $M_1 - M_0$

Percentage of Filtration (%) = $\frac{M_1 - M_0}{M_0} \times 100\%$

Pre-Filter: Fibre Filter

Mass of Fibre filter before welding: 14g,

Table 4.2: Analysis of Fibre Filter in a Double Filtration System

S/N	No. of Welding Electrode	Time (min)	Initial Mass of Filter M_0 (g)	Mass of Filter After Welding M_1 (g)	Mass of fumes trapped $(M_1\text{-}M_0)$(g)	% of Filtration $\left(\frac{M_1 - M_0}{M_0}\right) \times 100$
1	3	15	14	14.7	0.7	5
2	6	30	14	15.5	1.5	10.7
3	9	45	14	16.4	2.4	17.2
4	12	60	14	17.2	3.2	22.9

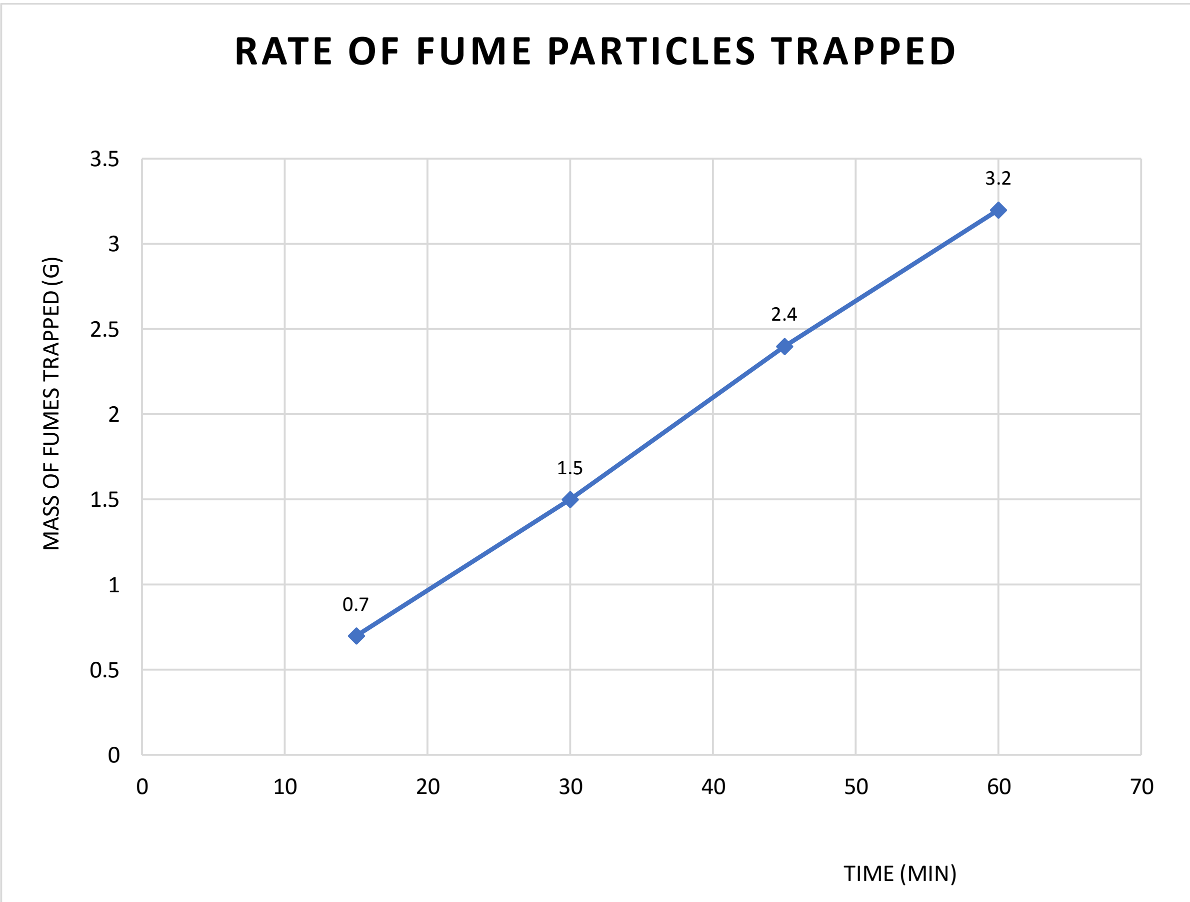

Figure 4.1: Analysis of Fibre in a Double Filtration System.

The experimental result obtained from the pre-filter with Fibre as the Filter material in a double filtration system are shown in Table 4.2 above. Before welding the mass of fibre filter was 14g but after the completion of 15 minute time interval of which active welding operation was carried out, using 3 electrodes, the mass of fibre filter was increased as 14.7g in which 0.7g of fume particles were trapped. Hence it is concluded that about 3.2 g of toxic content present in the welding fumes at the end of 60 minute were trapped through the fibre filter. Figure 4.1 present a graphical representation of masses of welding fumes particles trapped over a duration of 15, 30, 45 and 60 minute time interval

A straight-line graph which denotes an increase in mass of fume particle with time of active welding operation.

Main Filter: Cotton Cloth Filter

Mass of Cloth Filter before welding = 11g

Table 4.3: Analysis of Cotton Cloth Filter in a Double Filtration System

S/N	No. of Welding Electrode	Time (min)	Initial Mass of Filter M_0 (g)	Mass of Filter After Welding M_1 (g)	Mass of fumes trapped (M_1-M_0)(g)	% of Filtration $\left(\frac{M_1 - M_0}{M_0}\right) \times 100$
1	3	15	11	12	1	9.1
2	6	30	11	12.9	1.9	25.5
3	9	45	11	14.1	3.1	28.2
4	12	60	11	15.4	4.4	40

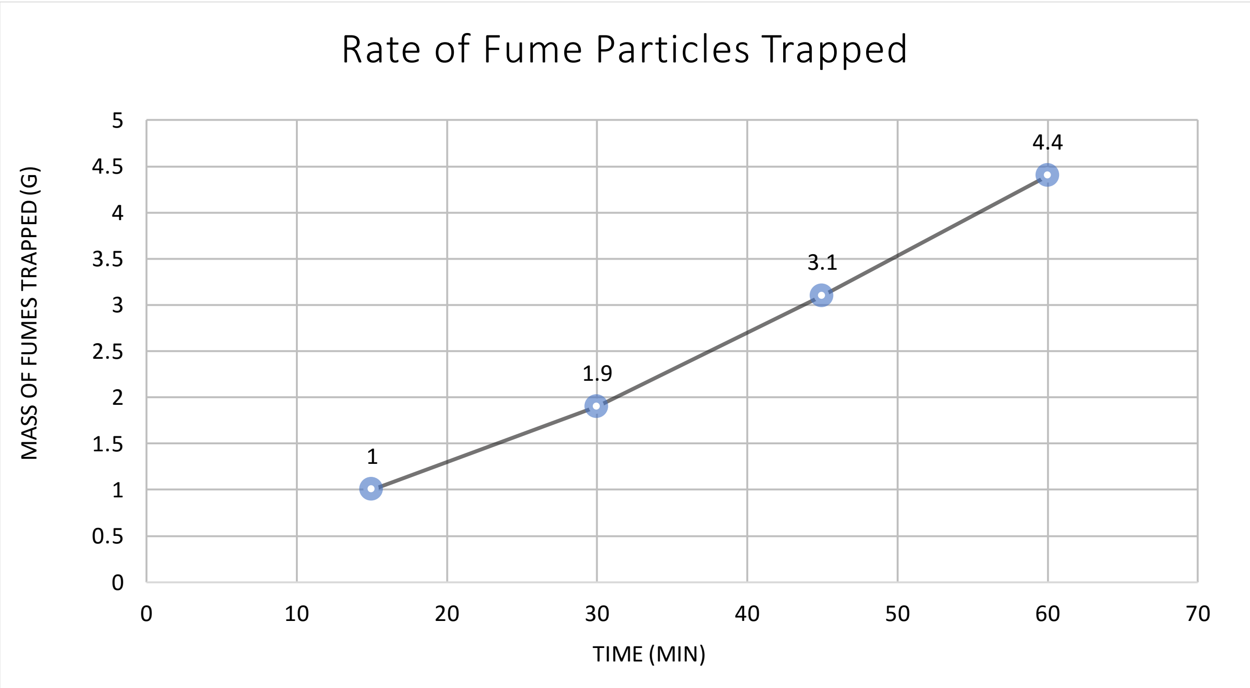

Figure 4.2: Analysis of Cotton Cloth in a Double Filtration System

The experimental result obtained from the main filter in which Cotton Cloth was used as the Filter material in a double filtration system are shown in Table 4.3 above. The Cotton Cloth have an initial mass of 11g before the process of welding. At 15 minute of active welding operation in which 3 electrodes were used, the mass of the cotton cloth increases to 12g. This process continues with the mass of cotton cloth increasing up to 15.4g at the end of 60 minute of active welding operation with 12 electrodes used. The graphical representation of masses of fume trapped during 15, 30, 45 and 60 minute time interval of which active welding operation was carried out are shown Figure 4.2 above, which also give a straight-line graph which denotes an increase in mass of fume particle with time of active welding activity.

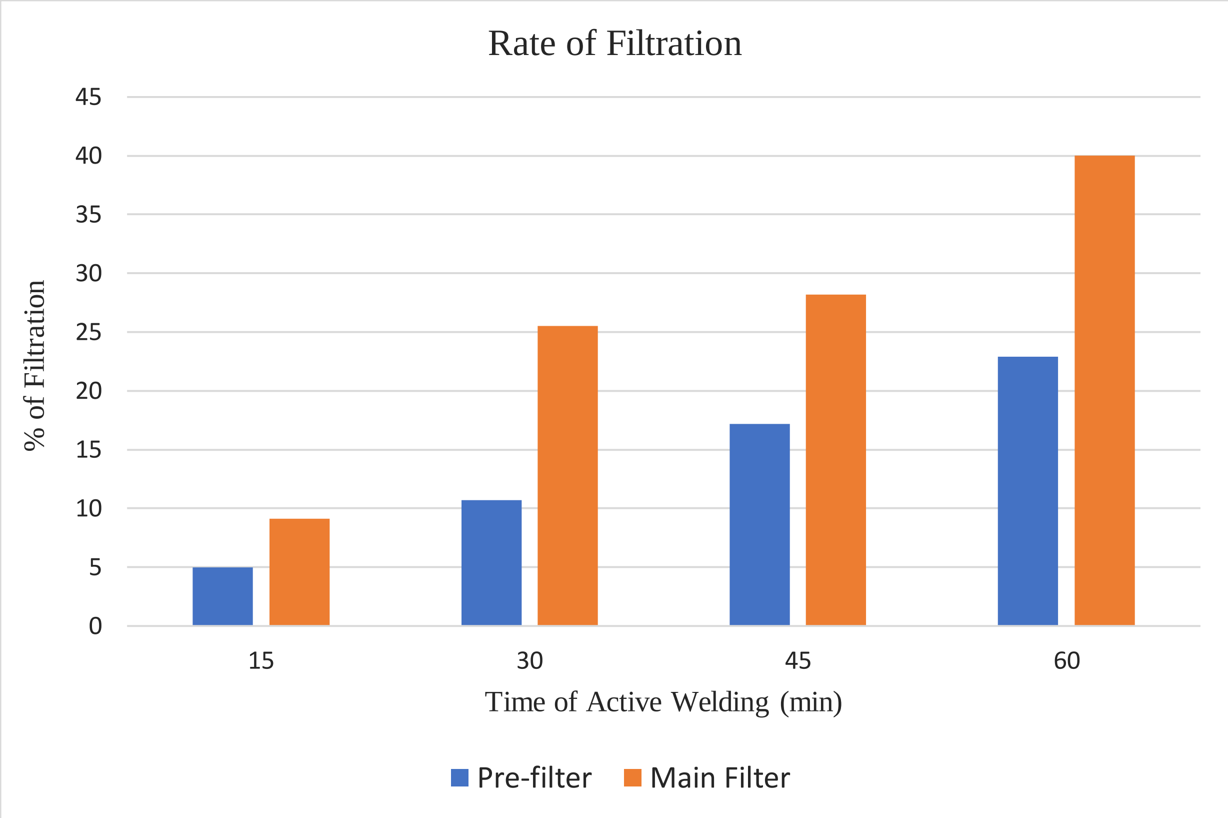

Figure 4.3: Analysis of Double Filtration System

Figure 4.3 shows an increase in the percentage of filtration of the pre-filter and main filter with every 15 minute increase in the time interval of active welding operation. It was observed that the main filter (cotton cloth) was able to capture larger mass of fume particles and record a higher percentage filtration of welding fumes as compare to pre-filter (fibre) over each 15 minute time interval, since it is designed to capture the majority of fumes particulates from welding and its allied process, due to the smaller spot holes size of the cotton cloth filter material.

V. Conclusion

After completion of the design and fabrication of the automatic fume extractor prototype which made use of venturi effect to generate enough negative pressure at the suction nozzle needed for adequate capture of welding fumes formed during welding operation, it was observed that the effectiveness of the extractor is dependent on performance of the centrifugal blower, the type of filtration system, filter material and other factors. During the course of the study an experimental test was carried out to of the filtration system in the automatic fume extractor. The result obtained from the analysis of the Double filter system of the fume extractor are as follows:

- The Cotton Cloth with an efficiency of 40% and 4.4g of fume particles trapped per hour is a better filter material compared to fibre which has an efficiency of 22.9% with 3.2g of fume particles trapped per hour.
- The main filter material (cotton cloth) was able to capture larger mass of fume particles; as it is designed with small spot holes to capture majority of fume particulate generated from welding which are not captured by a pre-filter (fibre).

- It also shows that the mass of filtrate captured by the fume extractor is dependent on the number, type and grade of electrode used, the supply voltage and duration of welding operation.

This study presents an innovative solution to the problems associated with welding fumes and gases during welding and other allied processes involving fume formation. It also reveals the types of fume and gas, their source and the severe effect they have in the health of welders. The utilization of the fume extractor will curb the problems associated with welding fumes by making Akwa Ibom State University Mechanical Engineering Workshop safe and healthy for welders, lecturers, technologists and students.

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